This "promoter" effect of water could be predicted on the radiation theory, since the chemical similarity of water and the aliphatic alcohols would lead to similar spectra in the infra-red region.

The curve for reduction by carbon monoxide at a temperature of 156° (not given in figure) shows a slight departure from the logarithmic law, presumably due to traces of water in the ethyl alcohol.

The two curves for hydrogen reductions (*loc. cit.*) are included in order to discuss them in the present connection (curves XIII, XIV, fig. 3).

The low activity of the catalyst prepared by hydrogen must be attributed to the well-known retention of hydrogen by the reduced copper, which is consequently "poisoned." The catalyst is not completely covered with hydrogen, as the "water-effect" is very marked on both curves. Hydrogen has absorption bands in the infra-red at 0·6 μ and at 1·2 μ, so that it would not be expected to act as a catalytic agent in the dehydrogenation, nor apparently is the radiation from the underlying copper able to act to any considerable extent on alcohol molecules across the hydrogen layer.

The work is being continued, with a view to finding the effect of admixed metals and oxides on the catalyst.

A Reciprocating Expansion Apparatus for Detecting Ionising Rays.

By Takeo Shimizu.

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The present investigation was undertaken for the purpose of obtaining a very sensitive method of detecting ionising rays, such as X-rays and rays from radio-active substances. An electroscope or electrometer, in combination with an ionisation chamber, even if the required sensitiveness were obtained, would not distinguish between the effects of a single ray and of two or more which entered the chamber simultaneously. In order to attack certain problems relating to the structure of ethereal waves and other delicate questions, it is necessary to have some means of detecting and discriminating individual rays. Mr. C. T. R. Wilson's beautiful method of making visible the tracks of ionising rays in gases* affords us the most powerful means for that purpose, and the writer accordingly tried to obtain a modified form of the original apparatus, such as could be readily used for various experiments.

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* 'Roy. Soc. Proc.,' A, vol. 87, pp. 277–292 (1912).

One important quality such apparatus should possess is the ability to correlate the number of tracks which are registered by it with the time interval during which the rays which produce them are emitted. With the original method, the expansion takes place so suddenly that it is difficult to determine this interval with accuracy, although it must be remembered that such suddenness has the merit of yielding well defined tracks at the moment of expansion. Another point is that the possibility of registering tracks, by producing the appropriate supersaturation of the gas in the cloud chamber, should be available continuously for the few hours which is usually required for any series of observations.

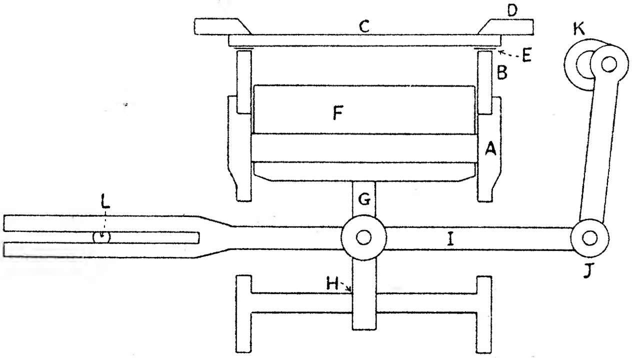
As it seemed difficult to provide a means to keep a volume of air constantly at a high supersaturation (which would be the most satisfactory way if it were possible), attempts were made to comply with the above conditions by using the original method of expansion, repeated at a convenient frequency, and also at a moderately slow rate of expansion.

There exist a number of imaginable mechanical and physical difficulties even for this simple method. It was doubted whether such a slow expansion would be good enough for the formation of a water drop around an ion. It was also expected that the air might become too dry after a number of expansions, the drops carrying much of the moisture to the bottom, and that such repetition of expansion might create a turbulent motion of air and distort the individual tracks. But, after some trials, it was found that the difficulties of the method were not so serious as had been feared.

The actual apparatus so far constructed is very similar to that of the original method, the chief difference being only in the mode of working the plunger or the piston. Instead of adjusting the position of the plunger before each expansion, according to the expansion ratio desired, and then letting the air pressure on the plunger suddenly press it down, a mechanical connection is made from a prime mover to the piston, so that the latter makes a reciprocating motion between two definite positions. The nature of the motion has much to do with the distinctness of the tracks, but, so far, an approximately harmonic motion has been used, because of its mechanical simplicity. The frequency of reciprocation can be anything from one to five or more per second, but the best number for use seems to be about two per second. Another feature with the present apparatus is a commutator, which establishes and destroys an electrostatic field between the upper and the lower surfaces of the chamber in synchronism with the piston.

The main parts are sketched in the figure.

A is a brass cylinder of suitable size fixed in position. B is a glass cylinder of the same inner diameter as A, and is fixed in A so that the inner walls of the two make one continuous surface. C is a circular glass plate, which forms the upper boundary of the chamber, and is firmly pressed down by a brass ring, D, large enough not to obstruct the view through C. E is a thin copper ring with an electric lead. All the surfaces of contact of the various parts of the chamber are made air-tight by putting thin rubber sheets cut into ring shape between, and applying a pressure through D by means of set screws. F is a brass piston of sufficient length, with an effective leather packing at its lower end. The proportions are such that the upper surface of the piston reciprocates within the lower half of the glass cylinder, while the packing always remains well inside the brass cylinder. The body of the piston must be as closely fitting as possible to the cylinder, but must not touch the inner surface of the glass walls at any point. It is important that the sliding surface between the packing and the cylinder be air-tight all through the stroke, and it was found satisfactory to use tap grease as lubricant, care being taken that it did not contaminate the glass walls. The piston is connected to a rod, G, which is guided by a stationary hole, H, in the base of the apparatus. A horizontal rod, I, is passed through G near the centre of its length and pinned to it. One end, J, of this rod is connected to a horizontal shaft, K, which is driven by a motor, by means of an arm and a link; J thus executes a rocking motion when the shaft rotates. At the other end it is split into two, and is penetrated by a horizontal stationary pin, L, which serves as a fulcrum. This pin, although fixed in position when the apparatus is properly running, is capable of adjustment in a horizontal line passing through the axis of the cylinder. The dimensions of all other parts being fixed, the position of this pin will determine the amount of stroke of the piston, that is, the ratio of expansion of the air, and it is convenient to be able to adjust this ratio while the apparatus is running. Although a moderately wide range of the ratio gives



equally good results, and the ratio which is supposed to be the best on one occasion will slightly differ from that on another according to the temperature of the room, the humidity in the chamber, the frequency of the reciprocation, and so on, 1·7 may be taken as not far from the best mean ratio. Too small an expansion often leaves the tracks incomplete or diffuse, while a too large one spoils them by the formation of a general cloud.

The mean height of the air space in the chamber has also a great deal to do with the result, and it is better to make it small, for the reasons that, with a shallow chamber, water drops will settle down to the bottom quicker, and the air will be less subject to disturbing motion, other conditions being the same. About 1 cm. seems to be a convenient height.

The upper surface of the piston is a little recessed from its edge, and is filled with blackened moist gelatine (about 15 grm. of dry gelatine and a little Indian ink in 100 c.c. of water), and the lower surface of the glass roof of the cloud chamber is coated with well conducting moist gelatine (about 10 grm. of gelatine and 2 grm. of copper sulphate in 100 c.c. of water), care being taken to let the copper ring (E) and the gelatine film make good contact with each other all round the circumference. It is better to give the gelatine films a moderate thickness (1 mm. or more), to avoid quick drying when the cover is temporarily removed for other purposes. When the gelatine surfaces either collect some dust particles or become too dry, the surfaces may be wiped with moistened soft cotton. To make sure that the transparent lining on the cover is of uniform thickness so as not to distort the image of the tracks, it is convenient to look, while the gelatine is still fluid, at the two images of a distant bright source reflected from the surfaces of the gelatine and of the glass, and adjust the level so that the two images coincide. The cylindrical surface of the chamber is simply cleaned and left uncoated.

The shaft (K) is provided with a disc-shaped commutator (not indicated in the figure), composed of two insulated sectors, one permanently earthed, and the other kept at a negative potential of 200 volts or more. A stationary brush, which is connected to the lead of the copper ring (E), makes contact with those sectors alternately. In order to be able to adjust the relative durations of these contacts, while the commutator is rotating, a curved line is used instead of a straight radial line for one of the boundaries between the two sectors. The frame of the apparatus, and, in consequence, the piston, are permanently earthed. The phase of the commutator is adjusted so that the air space in the chamber is subjected to an electrostatic field, commencing at the beginning of the upward stroke, and ending at a certain stage of the following downward stroke, when the air acquires the supersaturation just sufficient to form a cloud on ions. This stage is arrived at when the expansion is about half completed, although of course it depends upon the amount of stroke and other conditions.

If no electric field is applied at all, rays which entered into the chamber prior to this stage will appear as diffuse bunches, instead of sharp lines, owing to the spontaneous diffusion of ions, the diffuseness depending upon the age of each track at the moment of critical supersaturation. These diffuse clouds are not only unsuitable for observation but hinder also the growth of younger tracks, as they absorb the vapour about them and reduce the supersaturation. The electric field serves to remove all the ions generated between two successive supersaturations, as well as those remaining since the previous expansion. During a supersaturation the chamber must be free from electric field, because the ions on a track of ray will be pulled apart from their original positions along the direction of the field, according to the sign of their charge, before they lose their mobility by accumulating a sufficient amount of water. The distance they travel in this way is not the same for all ions in a given field, but seems to be subject to a certain continuous distribution law. Hence the appearance of an α-ray track is not a line but a vertical ill-defined sheet of cloud, densest along a middle line where the ray passed originally. Thus it is important to destroy the field at the right moment, and this is done by adjusting the brush while the expansions are going.

When the apparatus is ready for use, it is convenient to test it by putting a small piece of metal sheet with a trace of polonium upon it on the inner surface of the glass cylinder. After the cover has been tightly screwed down the room is darkened and the chamber illuminated with a horizontal parallel beam of light. For eye observation a half-watt lamp with a condenser affords a convenient source. For photographing, a carbon arc or some other intense source is necessary. When the source produces a noticeable amount of heat, care must be taken to cool the beam by inserting a water trough before it reaches the chamber. Two diaphragms are used with advantage to cut off divergent rays so that the beam nowhere touches the two opposite horizontal surfaces of the chamber. It is the upper half of the cloud chamber that produces the best defined tracks, so that both the ionizing rays and the beam of light may be confined to that part only.

When the chamber contains fresh atmospheric air the strokes of the piston will simply make the water vapour collect upon dust particles floating in it and a dense uniform cloud will be seen at each expansion. But this will subside after a small number of expansions, the central portion of the chamber being the first to become free from cloud. If there be any slight leakage of air into the chamber it will at once make its appearance as a stream of cloud which indicates the position of the leak; this can generally be easily rectified. When there is leakage of electricity across the inner surface of the side walls as a result of condensed moisture bridging the two opposite surfaces, a dense fog will also appear; this can be distinguished from the air leakage without difficulty.

Reciprocation of the piston always creates a slowly moving vortex ring in the air, co-axial with the cylindrical wall and situated close to it. The sense of rotation is such that the air next to the wall travels upward. The main body of the air including the centre is practically free from motion of this kind, and the tracks keep their form for several expansions, appearing and disappearing as the reciprocation goes on, unless they are speedily swept away by a sufficiently strong electric field.

It is likely that some of the drops coalesce with each other when the track is a dense one, like that of an α-ray, and the drops are allowed to grow large enough. The result is that the free surface is decreased and the evaporation much retarded, and the tracks are apt to survive many expansions in spite of the intermittently applied electric field. This is disadvantageous because new rays passing near them cannot collect sufficient water, and often appear as discontinuous tracks, or look as if they started at a considerable distance from the source. A weak source of rays is always advantageous in this relation, for the chance of two rays passing the same region one immediately after another is small.

It is perhaps worth mentioning here some of the peculiarities observed about the cloud tracks. If the electric field is not cut off during the period of condensation, the track of an α-ray is spead out into a vertical sheet as stated above. And if the field is of the right magnitude a sharply defined clear space can be seen across the sheet along the original direction of the ray. The contrast in sharpness between its boundaries and the upper and the lower edges of the sheet is remarkable, which perhaps tends to show that there is a definite maximum in the size of the drops when first formed.

Very intense and continuous electric fields were once tried, in order to see if it were possible entirely to stop the appearance of tracks by rapidly pulling the ions to the walls before they could grow up into drops. This was done to see if it might be possible to limit sharply by means of the commutator alone the periods during which cloud tracks were formed. This stage was arrived at with a field of the order of 1,000 volts per centimetre, but at the same time the number of neutral water drops, which usually exist to a certain extent throughout the chamber, increased considerably, so as to form a general cloud, and the rays left narrow vertical clear spaces along their tracks. Thus a kind of reversal of effect takes place when the field is increased, a vertical sheet of cloud in clear space being replaced by a vertical clear space in a cloud.

The above method having proved to be an inconvenient one for confining the production of cloud tracks to a definite short interval during each cycle, a small mechanical shutter, placed in the chamber and worked from outside automatically with a small magnet, which exposes the source for a predetermined short interval during the supersaturation, was used for the investigation of α-rays. More penetrating rays were flashed through a window in the wall from outside.

For the cloud-forming substance other liquids than water, such as alcohol and petroleum, were also tried. They give about the same results as water, so far as the general appearance of the tracks is concerned.

Conclusion.

There is no doubt that Mr. C. T. R. Wilson's original apparatus is superior for obtaining the most accurate shape of each track. It is mainly as a detector that the present one is likely to come into use. If the circumstances are favourable to its use, an apparatus of this type can hardly be surpassed by any other instrument in sensibility, for the simple reason that it can detect the elementary charge. The other relative merit that this type possesses over the electroscope-ionisation chamber system is that with the latter the natural ionisation in the chamber always puts a limit to the practical sensibility, while with the former one can differentiate to a large extent the genuine from the stray rays by their shape and size. For instance, an α-ray track observed during an ordinary X-ray measurement can be left out of account.

In conclusion, the writer wishes to express his sincere gratitude to Sir E. Rutherford, in whose laboratory the present work has been carried out, for his kind encouragement and advice. His cordial thanks are also due to Mr. C. T. R. Wilson, whose keen interest and advice made the work possible, for his unfailing kindness.